REVIEW DRAFT

Snake River Chinook Parr-Smolt Survival and Habitat Quality Indices

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Abstract

Using data on releases and recoveries of naturally produced, juvenile spring/summer chinook salmon (*Oncorhynchus tshawytscha*), and indices of land use/vegetation and road density, we show that there is a close association between land use patterns and juvenile survival. Parr tagged and released in wilderness areas in the Snake River drainage have the highest survival during their last 6-9 months of freshwater residence. In contrast, those tagged in young, dry forest lands have the lowest survival from release in the summer prior to downstream migration to subsequent detection at mainstem Snake dams the following spring. Similarly, fish tagged in areas of low road density have substantially higher overwintering survival than those tagged in areas where road density is high.

Although the number of tagged fish in the sample exceeds 150,000, the size of individual release groups was often on the order of 100-200 parr, with recoveries at dams an order of magnitude lower. One consequence of this is that parameter estimates may have skewed distributions. Therefore, we bootstrapped 1000 samples from the original data (with replacement), and used these to estimate distributions of model parameters. In addition, we used three functional forms to relate land use indices to fish survival: linear, logistic, and Poisson. The three functional forms all gave similar results. Since the release sites vary widely in elevation and distance to the first dam (where fish are detected), we included elevation and distance as independent variables. Year of tagging, treated as a factor variable, was used as a proxy for changing climatic conditions. In addition, size at tagging was also included. The models were developed and calibrated using fish released from 1988-1996, inclusive.

We conclude that in the study area there is a close association between the habitat quality indices and juvenile chinook survival. Since the fish are listed under the Endangered Species Act, this may suggest possible changes in land management in the region.

Introduction

Habitat quality and land use patterns are widely believed to affect salmonid survival. However, establishing empirical relationships between objective indices of land use practices and fish survival has proven to be very difficult. In part, this is because the relationships – if indeed they exist – are inherently complex, and may vary over time due to changing climatic conditions or other factors. In addition, it is difficult, time-consuming, and expensive to measure juvenile fish survival over areas that differ in habitat quality and (hypothesized) fish survival. The present analysis was inspired by work done by Achord and Sanford (1996). In their analysis, they related overwintering survival of marked juvenile salmon to their own ratings of habitat quality. While one might think that analyses of this type would be fairly common, theirs was the only example we could find that related measured survival to habitat quality.

A partial survey of published literature shows many examples of habitat surveys (e.g., Bisson and Sedell [1984], McIntosh et al [1994], Sedell [1984]). In addition, many studies have related salmonid presence/absence to various habitat indices (e.g., Chapman and Knudsen [1980], Everest and Harr [1982], Platts and Nelson [1988]). In addition, a few studies have examined the influence of fine sediments and other specific stressors on life-stage survival [e.g., Platts et al [1989]). Finally, the Carnation Creek studies of the effects of logging on coho and chum survival [E.g. Hartman et al [1984], Scrivener [1987]) and the Alsea watershed studies (Moring and Lantz [1975]) did examine the effects of measurable habitat variables on coho survival, as opposed to habitat preferences. So far as we know, however, there have been no survival/habitat quality studies for chinook, although they have been proposed by Walters et al (1989).

In the work described here, we were able to take advantage of a 10-year time series of juvenile tagging and release information. Since 1988, the Bonneville Power Administration (BPA) and the National Marine Fisheries Service (NMFS) have sponsored tagging studies in the Snake River, a major tributary of the Columbia. As one part of the studies, each summer and fall, 1-year old spring/summer chinook (*Oncorhynchus tshawytscha*) parr are collected and tagged in rearing areas upstream from Lower Granite Dam. The Passive Integrated Transponder (PIT) tags have individual "serial" numbers, so the subsequent capture history can be recorded for each fish. The following spring (from roughly April to June), the smolts are detected at Lower Granite, Little Goose, and McNary dams, as they begin their migration to the ocean. The data are collected primarily to assess survival during the spring migration. However, because the fish are tagged (and, by assumption, overwinter) in a variety of habitats, it is possible to assess how survival from summer/fall tagging to recovery the following spring varies with indices of habitat quality.

Following listing of spring/summer chinook under the Endangered Species Act (ESA) in 1993, the stock has received considerable attention from regional researchers. One aspect of the research is the Plan for Testing and Analyzing Hypotheses (Marmorek and Peters, 1997). As part of that work, biologists from the Idaho Department of Fish and Game and the Oregon Department of Fish and Wildlife (C. Petrosky and H. Schaller, respectively) assessed the quality of overwintering habitat for approximately 16 spring/summer chinook stocks spawning above Lower Granite Dam. The purpose of their assessment was to see if there was a relationship between habitat quality and life-cycle survival (from spawner to adult recruit to the Columbia). A Categorical Regression Tree (CART) analysis by D. Lee of the US Department of Agriculture Forest Service established a close correspondence between their habitat ratings and land use/vegetation cover data developed as part of the Eastside Assessment (Quigley and Arbelbide, 1997, Vol. 3). The main purpose of the CART analysis was as a check on the agencies' qualitative habitat assessments.

We used this information to investigate the relationship between habitat and overwintering survival. More than 300,000 parr were tagged in their rearing streams between 1988-96. Of these, over 150,000 were tagged in areas where the habitat indices have been developed. However, as noted above, the data were developed for other purposes. As such, the experimental "design" is far from balanced in many respects. It is certainly not a random sample with regard to land use. Neither is it balanced with respect to other factors that may affect juvenile survival, including size of fish at tagging, distance to Lower Granite Dam, or elevation of overwintering areas. Therefore, we used these factors were used as explanatory variables in the statistical models to help explain survival. In addition, to account for year-to-year variation in survival due to climatic conditions and other factors, we used year of tagging as a factor or classification variable.

Data

Tagging data were retrieved from PITAGIS (PSMFC, 1998) for each of 29 tagging sites, for a period of up to 10 years. Figure 1 is a map of the tagging locations. Table 1 shows the total fish tagged for each site for the entire 10-year period, as well as the number of fish not seen again, seen only below Lower Granite Dam (LGR), detected in smolt bypass systems at both LGR and lower river dam(s), and transported at LGR. The table also shows the Cormack-Jolly-Seber

(CJS) estimates of sampling efficiency and survival to LGR. See the Methods section for details of the CJS calculations. Note that this represents somewhat less than one half of the total number of overwintering spring/summer chinook tagged in the Snake. At this point, we do not have habitat quality indices for the other tagging sites, although these could be developed.

The data in the table may give a more optimistic picture of sample size than is actually the case. Table 2 shows the number of fish tagged at each site in 1988-96. Only two sites – IMNAHR, on the Imnaha River, and SECESR, on the Secesh – have releases in all years. In addition, many of the release groups, defined here as fish released in a given year at a given site, are often quite small, with many groups being less than 200 fish.[1] We suspected that the law of small numbers would probably apply: because of the small number of detections, parameters estimates would be ill-behaved. For this reason, we decided to bootstrap from the 154,864 individual release-recovery records (Efron, 1981), one for each tagged fish, rather than relying on assumptions about the distributions of survival and sampling efficiency proportions.

We considered three different ways to represent habitat quality of the over-wintering sites. The first was to use subjective habitat quality ratings developed by Idaho and Oregon state fisheries biologists. However, we were concerned that these ratings might not be reproducible, since different biologists evaluating the same stream reach might arrive at different conclusions about habitat quality. We therefore rejected this approach in favor of a second one. We decided to employ a "cluster" variable developed by D. Lee of the USDA Forest Service. The cluster variable in Table 4 is based on data developed by federal land management agencies for their assessment of land management in the Columbia Basin east of the Cascades (Quigley and Arbelbide, 1997, Vol. 3). It is a summary of land use patterns on a 1 KM^2 grid for the over-wintering areas. It summarizes both land ownership and vegetation patterns in a single variable. Five habitat cluster values are represented in our Passive Integrated Transponder (PIT) tag release samples: AG, MDRY, TRAN, WILD, and YDRY. These cluster variables were found to be the best predictor of the habitat ratings done by Oregon and Idaho state fish and wildlife agency personnel for the 36 spring/summer chinook index stocks that spawn in the Eastside Assessment area. The clusters apply to over-wintering habitat, as distinct from spawning and early rearing areas. We used them as factor variables in the regression models.

The third method is somewhat simpler than the land use cluster approach. Note from Table 4 that land use and road density are often correlated with one another. For example,

[1] Note that the number of recoveries at LGR and other dams will typically be an order of magnitude lass than the releases. See the "Totals" row in Table 1.

wilderness areas generally have very low road densities, while densities in agricultural areas are higher (see Figure 2). Therefore, we used a second set of models which employ road density in place of the cluster variable, to represent the degree of disturbance in habitat. The intent in using road density was to employ a simple measure of habitat quality that did not depend on subjective quality assessments, even indirectly. We transformed road density by using it's natural log, to make the variable's distribution somewhat closer to normal distribution (see Figure 3).

Methods

Because the estimates are bootstrapped from the 154,864 individual release records (Efron, 1981), it may be useful to think of the estimation procedure as operating in a large "DO" loop. Schematically, one might think of the loop in the following way:

1. Do I = 1 to 1000
2. Draw a sample (with replacement) of 154,864 release records from the population of 154,864.
3. Calculate sampling efficiency and survival for each group, where a group is defined to be all fish released at a particular site in a tagging season (July-December).
4. Estimate three GLM models of survival as a function of habitat classification or road density and other independent variables (length at tagging, etc.). The models assume three different link functions: linear, logistic, and Poisson.
5. Record parameter estimates and other model output.
6. Return to top of loop.

Since we bootstrap the results, we do not need to assume any particular distribution(s) for the parameter estimates. Instead, we simply plot the frequency distribution of the 1000 estimates, and assess what proportion of the estimates lie to either side of zero, as in the example of Figure 4.

As noted above in Step 3, the first calculation is to estimate sampling efficiency and survival, denoted as phi(t,i,j) and S(t,i,j), respectively. The "t" denotes tagging year, "i" tagging site, and "j" the bootstrap draw (from 1-1000). In order to calculate sampling efficiency and CJS survival for each group, six numbers are needed (we drop the "t,i,j" subscript in equations 1-3 for notational simplicity). In the jargon of the recapture survival literature, we have a three-event study: tagging in the subbasin (event 1), detection (and perhaps removal) at Lower Granite (event 2), and detection at one or more lower river dams (event 3). Removal refers to smolts that are transported at LGR by barge or truck. The mutually exclusive, exhaustive counts required are:

N(1,0,0), the number tagged (event 1), and never seen again;

N(1,2,3), the number tagged (event 1), seen at Lower Granite (event 2), and seen at one or more lower river dams (event 3);

N(1,2,0), the number tagged, seen at Lower Granite, returned to the river, and not seen thereafter;

R(1,2,0), the number removed (transported) at Lower Granite;

N(1,0,3), the number tagged, not seen at Lower Granite, but seen at one or more lower dams; and

N(0), the total number of fish tagged at a release site each year (the sum of the above counts).

The identification of fish is made possible by the fact that the PIT tags have unique identifiers or serial numbers, which can be read by detectors at the mainstem Snake dams. The probability that a fish is transported at LGR can be expressed as:

$$R = R(1,2,0) / \{R(1,2,0) + N(1,2,3) + N(1,2,0)\}. \qquad (1)$$

The numerator in (1) is the number of fish transported at LGR, while the denominator is the total number of fish detected at LGR. The probability that a fish will be detected at LGR is:

$$Phi = N(1,2,3) / \{ N(1,2,3) + (1-R) * N(1,0,3) \}. \qquad (2)$$

In (2), the numerator is the number of fish detected at both LGR and at one or more lower projects. The denominator is an estimate of the number of fish alive below Lower Granite, corrected for known removals. Finally, the probability of surviving to Lower Granite is:

$$S = [\{R(1,2,0) + N(1,2,0) + N(1,2,3)\} / N(0)] / Phi. \qquad (3)$$

In (3), the sum in curly brackets is the number of fish detected at LGR, N(0) is the total number released, and Phi is the detection probability, given that a fish is alive at LGR. Note the inverse relationship between sampling efficiency and estimated survival. Equations 1-3 draw heavily on Cormack-Jolly-Seber estimates, adjusted for known removals, as explained in the SURPH User Manual (Smith at al 1994). Recall that there will be one survival estimate for each year/release site/bootstrap combination.

The structure of the GLM models is reasonably straightforward. Variables are defined in Table 5. Note that habitat classification [the C(i)'s] and year of release [Y's] are classification or factor variables. The habitat classification has five different levels or values, one for each habitat cluster value in Table 4. The Y's has nine different levels, one for each release year, 1988-96. We represent the factor variables with **bolded** letters in equations 4a-9b to distinguish them from the continuous variables. In the actual estimation, "YDRY" and 1996 are the reference cases: they are set to zero to avoid perfect colinearity with the other classifications.

The linear model is straight-forward:

$$S(t,i,j) = b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + \mathbf{C} + \mathbf{Y} + \varepsilon(t,i,j) \qquad (4a)$$

where S(t,i,j) is estimated survival, and the $\varepsilon(t,i,j)$'s are assumed to be independently and normally distributed.[2] The b(i)'s, **C**'s and **Y**'s are estimated parameters. The estimates are weighted by the number of tags released from each site and tagging year. Each coefficient will have one estimate for each of the 1000 bootstrapped samples from the larger sample of 156,864 tagged fish. The "j" subscripts on coefficients, denoting bootstrap draws, are omitted for notational convenience. The linear model using the natural log of geometric mean road density is very similar to 4a:

$$S(t,i,j) = b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + b4 * G(i) + \mathbf{Y} + \varepsilon(t,i,j) \qquad (4b)$$

which simply substitutes road density for habitat classification. In the linear model, the S(t,i,j)'s are assumed to be normally distributed. Both 4a and 4b are estimated using weighted least squares, where the number in the release group is the weight.

The logistic models have a different form for the dependent variable, but are very similar in terms of the independent variables (IV's). Let $\theta(t,i,j) = R(t,i,j) / T(t,i,j)$, where R(t,i,j), recoveries at LGR, is assumed to have follow a binomial distribution. The R(t,i,j)'s are calculated from the CJS survival estimates and total releases, N(0). Then the logistic model is:

$$\mathrm{Log}\{\theta(t,i,j)/[1-\theta(t,i,j)]\} = b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + \mathbf{C} + \mathbf{Y} + \varepsilon(t,i,j) \qquad (5a)$$

In contrast to the linear model, the dependent variable in the logistic model is the logistic transform of survival. Therefore, although the form of the right hand side of the equation is very similar to the linear model, the interpretation of the parameters is very different. In the linear

[2] The importance of this assumption is reduced in this analysis since the model errors are not used to estimate the variance of the coefficient estimates.

model, the parameters are additive effects on survival, while in the logistic, they are multiplicative. Using road density instead of habitat classification, we have:

$$\mathrm{Log}\{\theta(t,i,j)/[1-\theta(t,i,j)]\} = b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + b4 * G(i) + \mathbf{Y} + \varepsilon(t,i,j) \qquad (5b)$$

Unlike the linear model, estimated number of fish surviving to LGR is assumed to be binomially distributed for the logistic model. The logistic models are estimated using iteratively reweighted least squares to account for the non-linear link function (McCullagh and Nelder, 1989).

Finally, for the Poisson model, the number of fish surviving to LGR is assumed to follow a Poisson distribution. The dependent variable is the number of fish surviving, calculated as total fish tagged in each group multiplied by the group's corresponding CJS estimate of survival for the group. The Poisson model therefore has the following form, following Cormack and Skalski (Cormack and Skalski, 1992):

$$E[n(t,i,j)] = \mu(t,i,j) = T(t,i,j) * \theta(t,i,j) \qquad (6)$$

Where :

t,i,j indexes release groups (year, site and bootstrap iteration);

n(t,i,j) is the number of fish in each release group surviving to Lower Granite;

E[n(t,i,j)] is the expected number of tagged fish from each release group expected to be found in the sample at LGR (assumed to follow a Poisson distribution);

$\mu(t,i,j)$is the expected number of fish recovered from release group *i*;

T(t,i,j) is the number of fish released in each group; and

$\theta(t,i,j)$is the probability that a fish from release group (t,i,j) is detected at LGR.

Equation (6) can be expressed as a log-linear model:

$$\mathrm{Ln}[\mu(t,i,j)] = \ln[T(t,i,j)] + \ln[\theta(t,i,j)] \qquad (7)$$

with variance:

$$\mathrm{Var}\,[n(t,i,j)] = \phi * \mu(t,i,j) \qquad (8)$$

The scaling factor, ϕ, is an estimated parameter.[3] The ln[T(t,i,j)] term in Eq. 7 is used as an offset, and the estimated parameter is constrained to equal one in the estimation procedure. The ln $\theta(t,i,j)$ term in Eq. 7 can be partitioned into effects due to habitat quality cluster, etc.

[3] The scaling factor ϕ is used to scale the variance of the estimates. Since we are bootstrapping to obtain parameter distributions, ϕ is not reported in the results. It's value does not affect the expected value of the estimated b's, only their variance.

The model estimated then takes on a form that is similar to the linear and logistic models, with the "θ" term decomposed into parameters for habitat class, road density, et cetera, as follows:

$$\mathrm{Ln}[\mu(t,i,j)] = \ln[T(t,i,j)] + b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + \mathbf{C} + \mathbf{Y} + \varepsilon(t,i,j) \qquad (9a)$$

$$\mathrm{Ln}[\mu(t,i,j)] = \ln[T(t,i,j)] + b1 * D(i) + b2 * L(t,i,j) + b3 * E(i) + b4 * G(i) + \mathbf{Y} + \varepsilon(t,i,j) \qquad (9b)$$

Because the ln[T(t,i,j)] term in 9a and 9b is an offset, the equations for the Poisson model essentially estimate the log of the proportion of fish surviving to LGR. As with the logistic model, the effects of the independent variables will be multiplicative. They are estimated using iteratively reweighted least squares (McCullagh and Nelder, 1989).

Results

Goddness of fit (r-square) statistics and the number of estimated parameters for the six models are shown in Table 6. The reported number of parameters is an average. This is because, in the course of bootstrapping from the release data, some release groups may be omitted because survival cannot be estimated for that group. This happens whenever Eqs. 1-3 have zeroes in their denominators. When this occurs, it may be impossible to estimate some parameters, since entire years or habitat clusters may not be present in a particular bootstrapped sample.

As can be seen from the table, both the habitat cluster and road density models do reasonably well in terms of explaining the variation in overwintering survival. In both cases, the number of parameters is fairly high relative to the number of release groups (averaging 150), but very modest in comparison to the 154,864 individual tagged fish.

Tables 7a and 7b show the bootstrapped distributions of parameter estimates for the cluster and road density models. The tables show the mean values of parameter estimates and, to the right of the means, the proportion of the estimates that are greater or less that zero. For example, for the linear model using road density (table 7b), the mean value of the parameter for elevation is –1.33E-06, and 72.1% of the 1000 bootstrapped estimates are less than zero. Distributions of the cluster parameters are shown in Figures 5a-5d, while those for road density are shown in Figure 6. Most are skewed to some degree, but none depart markedly from a normal distribution.

The cluster model results are surprisingly strong: for all three functional forms, the "AG" "MDRY" "TRAN" and "WILD" clusters differ from the reference cluster, "YDRY", in all 1000 bootstrapped runs. The parameter for elevation is greater than zero in all runs for all models, as is length at tagging. Distance to LGR has a parameter less than zero for all runs and models as well. In other words, it appears that there are strong differences in survival among the habitat clusters. Higher survival is associated with larger size at tagging and increased elevation, while lower survival is associated with greater distance to LGR.

Somewhat surprisingly, the “AG” habitat has the highest survival for all functional forms, with “WILD” ranking 2nd. We suspect that this, in turn, helps explain the positive sign for the elevation parameter: wilderness sites are generally at higher elevations, and one would expect higher survival in wilderness areas than in agricultural regions. We discuss this further below.

The year effects are usually consistent across models, as well. The parameters for years 1988-92 are always worse than the reference year, 1996, for all three functional forms. The parameter for year 1995 is better than the reference year for all functional forms, while the effects for 1993 and 1994 differ only for the Poisson model. In summary, 1988-92 had worse survival than 1996, 1995 had higher survival, and 1993-94 appear to differ little from 1996.

For the road density models (Table 7b), the results for distance, size at tagging, and the year effects are generally similar to those for the cluster models. The effects of road density are very strong: increased road density is associated with decreased survival for all three functional forms, for all 1000 iterations of the bootstrap. Increased elevation appears to have a weak, negative association with survival for all three functional forms. As with the cluster models, we suspect that this is due to correlations among the IV’s.

The correlations are displayed in Tables 8 and 9 for the cluster and road density models, respectively. For the cluster models, one can see that elevation has a correlation of 0.539 with “WILD”: wilderness areas tend to be located at high elevations. Similarly, the correlation between elevation and distance to LGR is 0.799: higher elevation sites are farther from Lower Granite Dam. From Table 9, one can see that higher elevation sites tend to have lower road density; the correlation between the two is –0.613. These correlations, of course, make it more difficult to separate the effects of the independent variables.

In an analysis with correlated independent variables, there are typically three choices for dealing with the problem. The first is to remove one of the variables from the analysis. Although we have not tried this approach with the data in hand, removing elevation from the models would be our first choice, since we suspect that it would not reduce the explanatory power of the models by much. The other strongly correlated pair is distance and road density. In this case, eliminating either one would almost surely result is a substantial reduction in explanatory power. The second possibility is to interact the variables, perhaps after transforming them so that the linear correlation is reduced. We have tried this with both the cluster and road density models. The results are very similar to those reported above: both habitat clusters and road density show strong relationships with survival. In addition, the wilderness areas indeed have the highest survival, after taking their higher elevation into account. A drawback to adding interaction terms is that they can add many parameters to the estimated models, and they may be correlated with the other IV's. The best alternative, of course, is to acquire additional data, and use it to try to separate the individual effects of the correlated variables. We discuss this in more detail in the next section.

Discussion

One should take care not to over-interpret these results. Although they suggest a strong association between land use patterns and overwintering survival, several caveats should be kept in mind when inferring causality from statistical associations. The first is the cross-sectional nature of the land use data. Although we have a 9-year time series of survival information, the land use indices are static: they vary across sites, but not over time. Therefore, the analysis does not directly address a common question in habitat enhancement: if I improve the habitat at a particular location, will the habitat change improve fish survival at that location? Instead, the analysis looks across locations with different land use indices, and shows an association between the indices and juvenile survival. Second, the scale of the analysis is quite broad. It examines 29 releases sites in 22 streams (several streams have more than one release site). In contrast, land management and habitat enhancement activities often affect individual watersheds or small portions thereof. This analysis cannot address what happens on such small scales. A third, related caveat is the scale of the land use indices. They are broad-based indicators of land management (habitat clusters) and the density of road networks. They make no direct attempt to measure more detailed patterns of land use. Given this, one should not be too literal in interpreting the results: an *x*% decrease in road density should not, by itself, be expected to result in a *y*% increase in survival. Rather, the road density is in all likelihood an indicator of other, associated, human disturbance (although roads may well have detrimental effects of their own). Along the same lines, one might expect that streamside disturbances would affect on survival more than disturbances within the watershed but well removed from the riparian zone. The indices we used do not address this scale at all; they consider overwintering habitat for each stream to be homogenous. Finally, although parr do migrate within subbasins (e.g., Keefe et al

1994), we have assumed that their habitat exposure can be indexed by the areas where they are tagged in the summer and fall. This may not always be true.

Having said this, however, we believe that one can draw some conclusions from the study. First, there appears to be a strong association between objectively measured land use patterns and overwintering survival. To the best of our knowledge, this is the first study of spring/summer chinook to demonstrate such an association. Therefore, the results should be viewed with a certain amount of skepticism. However, they appear to be in the direction one would expect intuitively. For the road density parameters, it is clear that increased road density is associated with decreased survival. The habitat cluster analysis does not conform quite so nicely with intuition. We had expected that wilderness areas would provide the best habitat, but that evidently is not the case: elevation, distance, and size at tagging being equal, agricultural areas appear to provide better habitat than do wilderness areas. However, as noted in the previous section, the independent variables exhibit fairly strong correlations with one another, and this explains some of the dissonance between our intuitive expectation and the analytical results.

With the above caveats in mind, what can one say about the effects that land management actions might have on survival? That is, if one is willing to assume that the associations identified in the analysis reflect a causal relationship, how would survival be affected by changes in habitat quality? While we do not believe that the results are presently strong enough to delve into this question in detail, a simple example may be warranted.

First, assume for the sake of discussion that one could somehow make a YDRY (young, dry forest) into a WILD (wilderness area) site. Based on the model results, how would survival be expected to change? Estimated overwinter survival for one YDRY area, the WENRSF site, was about 15.8% (from Table 1). Using the linear habitat cluster model, we see from Table 7a that the mean estimated parameter for WILD (with YDRY as the reference case) is 0.0551, so the expected change in survival for improving the site would be 5.5%, increasing survival to 21.3% (15.8 + 5.5). Expressed as a percentage of base case (15.8%) survival, it would be 5.5/15.8 or approximately 34.8%. Obviously, it seems unlikely that there are management actions that would make a young, dry forest into a wilderness area in any reasonable time frame, but the point overall is that substantial survival increases could result from changes in land management.

In order to strengthen the results, and to challenge the models with additional data, we believe that the study would benefit from extensions in several directions. First, the geographic scope could be expanded to include an additional 150,000 tagged parr. This would entail developing the habitat and road density indices for another 30-40 release sites. This would be a straight-forward undertaking. We hope that the additional release sites will display associations between the habitat quality and survival that are similar to the current study, a readily testable hypothesis. Second, one could expand the study to include fish tagged in the summer and fall of 1997, again with the expectation that they would display similar habitat-survival associations.

A third possibility would be to develop habitat indices specifically to “predict” fish survival. Recall from the Data section that the habitat classifications used here were designed to explain regional biologists’ ratings of habitat quality, rather than fish survival per se. They draw on a very extensive set of data originally developed as part of the Eastside Assessment (Quigley and Arbelbide, 1997, Vol. 3). These include information on vegetation, long-term average climate, soil composition, land management-ownership, and fire frequency, at a resolution of 1 KM^2. While one can only speculate at this point, it seems likely that other indices could be developed using the Eastside data that would provide better explanations of variations in chinook survival.

Finally, based on previous work (e.g., Paulsen at al 1997) we expect that it may be possible to replace the year effects with measured indicators of local climate, such as streamflows or drought indices. While climatic variation is obviously not the focus of the study, adding climate indices would be more parsimonious (in terms of the number of estimated parameters) and may be of interest in it’s own right.

Acknowledgements

YOUR NAME HERE IF I GET COMMENTS WITHIN THE NEXT FEW WEEKS.

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Table 1. Parr Tagged and Recovered, for Each Tag Site. LGR = Lower Granite Dam

	Total Fish Tagged, 1988-96	Tagged Fish Never Recovered	Seen Only Below LGR	Seen at Both LGR and Lower River Dam(s)	Seen at LGR, Returned to River, Not Seen Again	Transported at LGR	Cormack-Jolly-Seber LGR Sampling Efficiency	Cormack-Jolly-Seber Survival to LGR
Symbols For Eqs. 1-3	N(0)	N(1,0,0)	N(1,0,3)	N(1,2,3)	N(1,2,0)	R(1,2,0)	Phi	S
ALTULC	2,703	2,581	58	17	0	47	0.525	0.045
BEARVC	6,273	5,623	235	99	15	301	0.605	0.109
BIGC	6,683	5,819	322	162	20	360	0.600	0.135
CAPEHC	2,020	1,783	85	68	7	77	0.619	0.122
CATHEC	8,114	6,770	622	302	93	327	0.470	0.189
ELKC	3,862	3,441	163	89	16	153	0.573	0.117
GRANDR	8,285	7,069	517	226	30	443	0.544	0.155
IMNAHR	10,022	8,614	604	273	45	486	0.533	0.150
IMNAHW	1,682	1,348	160	103	26	45	0.465	0.223
IMNTRP	2,231	1,630	285	179	50	87	0.464	0.305
JOHNSC	826	715	51	24	0	36	0.541	0.134
LAKEC	1,195	1,053	57	38	13	34	0.526	0.135
LEMHIW	3,747	2,762	365	341	109	170	0.563	0.294
LOOKGC	7,574	6,415	512	350	88	209	0.502	0.170
LOONC	1,621	1,346	132	72	12	59	0.481	0.183
LOSTIR	6,935	5,717	556	230	59	373	0.487	0.196
MARSHC	8,150	7,234	317	150	10	439	0.639	0.115
MARTRP	9,827	7,483	927	792	73	552	0.583	0.247
MINAMR	4,565	3,823	343	192	31	176	0.500	0.175
SALEFW	1,346	1,151	85	71	10	29	0.531	0.154
SALREF	4,983	4,507	180	78	11	207	0.590	0.101
SALRSF	13,721	12,152	620	328	26	595	0.586	0.118
SAWTRP	5,680	5,078	264	98	39	201	0.478	0.124
SECESR	9,891	8,820	380	163	20	508	0.618	0.113
SFSTRP	4,903	4,366	276	138	56	67	0.402	0.132
SULFUC	4,154	3,718	165	47	5	219	0.598	0.109
VALEYC	10,087	9,469	286	79	2	251	0.531	0.062
WENR	819	696	54	37	7	25	0.518	0.163
WENRSF	2,965	2,529	194	133	22	87	0.517	0.158
Totals	154,864	133,712	8,815	4,879	895	6,563	0.542	0.147

Table 2. Fish Tagged for Each Site and Year

Tagging Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	Total
Tagging Site										
ALTULC	407	1,035	407	155	368	0	331	0	0	2,703
BEARVC	0	1,556	352	1,042	1,013	856	1,454	0	0	6,273
BIGC	0	2,023	723	1,001	733	721	1,482	0	0	6,683
CAPEHC	0	0	164	209	205	0	1,442	0	0	2,020
CATHEC	0	0	1,011	940	1,092	1,000	1,983	1,106	982	8,114
ELKC	0	16	246	462	628	998	1,512	0	0	3,862
GRANDR	2,982	0	0	0	915	1,909	2,349	103	27	8,285
IMNAHR	1,201	1,981	327	758	997	1,750	996	996	1,016	10,022
IMNAHW	0	0	0	0	0	686	0	996	0	1,682
IMNTRP	0	0	0	0	0	0	760	1,022	449	2,231
JOHNSC	0	0	0	0	633	0	193	0	0	826
LAKEC	0	0	0	0	255	0	405	135	400	1,195
LEMHIW	0	0	0	0	749	805	1,762	179	252	3,747
LOOKGC	0	0	0	0	0	1,954	3,570	2,036	14	7,574
LOONC	0	0	0	0	261	396	964	0	0	1,621
LOSTIR	0	84	1,006	1,107	995	724	1,001	977	1,041	6,935
MARSHC	0	2,495	859	981	999	1,248	1,568	0	0	8,150
MARTRP	0	0	0	0	0	6,218	3,329	280	0	9,827
MINAMR	0	0	0	0	988	996	996	996	589	4,565
SALEFW	0	0	0	0	0	198	1,040	108	0	1,346
SALREF	740	0	863	669	842	883	986	0	0	4,983
SALRSF	2,167	0	654	1,027	1,615	5,291	1,569	700	698	13,721
SAWTRP	1,762	0	1,387	0	740	101	1,134	556	0	5,680
SECESR	2,126	2,356	1,016	1,012	327	674	1,549	571	260	9,891
SFSTRP	0	0	0	0	0	0	2,465	1,083	1,355	4,903
SULFUC	0	2,504	0	210	712	0	728	0	0	4,154
VALEYC	2,177	2,493	1,024	969	1,026	848	1,550	0	0	10,087
WENR	0	0	0	0	178	212	259	170	0	819
WENRSF	0	0	0	0	552	786	740	825	62	2,965
Annual Totals	13,562	16,543	10,039	10,542	16,823	29,254	38,117	12,839	7,145	154,864

Table 3. Habitat Quality and Environmental Variables

Tag Site	Location (River Name)	Vegetation/Land Use Cluster	Distance from site to LGR, Kilometers	Elevation (Feet)	Geometric Mean Road Density, Km/Km^2	Ln(Road Density)
ALTULC	Alturas Lake Ck.	TRAN	768	6,733	0.12	-2.120
BEARVC	Bear Valley Ck.	WILD	632	6,632	0.03	-3.507
BIGC	Big Ck.	WILD	491	5,741	0.01	-4.605
CAPEHC	Cape Horn Ck.	WILD	629	6,713	0.04	-3.219
CATHEC	Catherine Ck.	AG	362	2,999	0.65	-0.431
ELKC	Elk Ck.	WILD	633	6,632	0.03	-3.507
GRANDR	Grande Ronde R.	YDRY	109	4,927	2.25	0.811
IMNAHR	Imnaha R.	TRAN	239	4,486	0.07	-2.659
IMNAHW	Imnaha R.	TRAN	209	4,486	0.07	-2.659
IMNTRP	Imnaha R.	TRAN	142	4,486	0.07	-2.659
JOHNSC	Johnson Ck.	MDRY	429	5,406	0.16	-1.833
LAKEC	Lake Ck.	MDRY	449	6,070	0.06	-2.813
LEMHIW	Lemhi R.	TRAN	595	5,784	0.4	-0.916
LOOKGC	Lookingglass Ck	YDRY	239	4,364	3.08	1.125
LOONC	Loon Ck.	WILD	555	5,925	0.01	-4.605
LOSTIR	Lostine R.	AG	290	3,418	1.33	0.285
MARSHC	Marsh Ck.	WILD	620	6,713	0.04	-3.219
MARTRP	Marsh Ck.	WILD	630	6,713	0.04	-3.219
MINAMR	Minam R.	WILD	280	5,142	0.17	-1.772
SALEFW	Salmon R. E. Fork	TRAN	712	6,322	0.16	-1.833
SALREF	Salmon R. E. Fork	TRAN	696	6,242	0.17	-1.772
SALRSF	Salmon R. S. Fork	MDRY	457	5,206	0.16	-1.833
SAWTRP	Salmon R. S. Fork	TRAN	747	6,611	0.13	-2.040
SECESR	Secesh R.	MDRY	431	6,070	0.06	-2.813
SFSTRP	Salmon R. S. Fork	MDRY	456	5,206	0.16	-1.833
SULFUC	Sulphur Ck.	WILD	605	6,358	0.01	-4.605
VALEYC	Valley Ck.	TRAN	757	6,552	0.15	-1.897
WENR	Wenaha R.	YDRY	204	4,058	0.09	-2.408
WENRSF	Wenaha R.	YDRY	207	4,058	0.09	-2.408

Table 4. Habitat Cluster Definitions

Cluster name	Principal Ownership and Use	Vegetative Composition
AG	Private agriculture	Agriculture, transitional areas
MDRY	USFS high impact, USFS moderate impact, USFS low impact and wilderness	Older dry forest, transitional areas
TRAN	BLM rangeland, private forests, USFS grazing land, USFS moderate impact	Transitional areas, mountain shrub lands, young conifer stands
WILD	USFS low impact and wilderness	Young confer stands, transitional areas
YDRY	USFS high impact, USFS low impact and wilderness, private forests	Young dry forests

Table 5. Variable definitions for bootstrapped models

Variable Name	**Definition**	**Continuous or Factor (Classification)**	**Values (for Factor Variables)**
C(i)	Habitat Class, release site i	Factor	See Table 4
G(i)	Natural log of geometric mean road density, km/km^2, release site i	Continuous	
Y	Year of Release	Factor	1988-96
D(i)	Distance from tagging site to LGR, Km, release site i	Continuous	
E(i)	Elevation of tagging site, feet, release site i	Continuous	
L(t,i,j)	Average length of parr at tagging, mm year t, site i, bootstrap iteration j	Continuous	
S(t,i,j)	Survival from tagging to LGR, year t, site i, bootstrap iteration j, adjusted for sampling efficiency	Continuous	
T(t,i,j)	Number of fish released, year t, site i, bootstrap iteration j	Continuous	
R(t,i,j)	Number of fish recovered at LGR, year t, site i, bootstrap iteration j. Equals **S(t,i,j) * T(t,i,j)**		

Table 6. Model Goodness of Fit Statistics

Model Form	Habitat Index	Average Number of Estimated parameters	Average R-Square	5th Percentile	95th Percentile
Linear	Habitat Classification	16	0.74	0.70	0.77
Logistic	Habitat Classification	16	0.62	0.62	0.69
Poisson	Habitat Classification	17	0.95	0.94	0.96
Linear	Road Density	13	0.68	0.64	0.71
Logistic	Road Density	13	0.61	0.53	0.66
Poisson	Road Density	14	0.92	0.91	0.93

Table 7a. Main Effects of Model Parameters – Habitat Cluster Models

Model	**Linear**		**Logistic**		**Poisson**	
	Mean Parameter Value	Proportion < 0 or > 0	Mean Parameter Value	Proportion < 0 or > 0	Mean Paramete r Value	Proportion < 0 or > 0
Parameter						
Elevation	2.3E-05	1	1.86E-04	1	1.54E-04	1
Distance to LGR	-1.8E-04	1	-1.54E-03	1	1.29E-03	1
Length at Tagging	4.42E-03	1	0.0316	1	0.0258	1
Clusters:						
AG	0.0859	1	0.674	1	0.563	1
MDRY	0.0398	1	0.316	1	0.260	1
TRAN	0.0194	1	0.106	1	0.0792	1
WILD	0.0551	1	0.428	1	0.354	1
YDRY	0	N/A	0	N/A	0	N/A
Release Year						
88	-0.0369	1	-0.333	1	-0.288	1
89	-0.0420	1	-0.363	1	-0.312	1
90	-0.0491	0.993	-0.303	0.965	-0.239	0.961
91	-0.0353	0.987	-0.274	0.971	-0.225	0.971
92	-0.0387	1	-0.247	1	-0.197	1
93	5.25E-04	0.455	0.0498	0.177	0.0539	0.931
94	0.00159	0.399	0.0567	0.113	0.0556	0.930
95	0.0390	1	0.271	1	0.221	1
96	0	N/A	0	N/A	0	N/A

Table 7b. Main Effects of Model Parameters – Road Density Models

Model	**Linear**		**Logistic**		**Poisson**	
	Mean Parameter Value	Proportion < 0 or > 0	Mean Parameter Value	Proportion < 0 or > 0	Mean Parameter Value	Proportion < 0 or > 0
Parameter						
Elevation	-1.33E-06	0.721	-1.26E-06	0.528	-4.19E-06	0.617
Distance to LGR	-9.0E-05	1	-7.4E-04	1	-6.1E-04	1
Length at Tagging	0.00416	1	0.0284	1	0.0228	1
Road Density	-0.0106	1	-0.0814	1	0.0668	1
Release Year						
88	-0.0504	1	-0.458	1	-0.398	1
89	-0.0536	1	-0.481	1	-0.416	1
90	-0.0602	0.993	-0.433	0.988	-0.355	0.986
91	-0.0236	0.979	-0.164	0.977	-0.133	0.975
92	-0.0442	1	-0.301	1	-0.244	1
93	-0.0045	0.743	0.00319	0.514	0.0127	0.649
94	-0.00573	0.981	-0.0160	0.632	-0.00869	0.571
95	0.0291	1	0.179	1	0.142	1
96	0	N/A	0	N/A	0	N/A

Table 8. Habitat Cluster Independent Variable Pearson Correlations, Entire Dataset

	Elevation	**Distance to LGR**	**Length at Tagging**	**AG**	**MDRY**	**TRAN**	**WILD**	**YDRY**
Elevation	1.000							
Distance to LGR	0.799	1.000						
Length at Tagging	-0.194	-0.076	1.000					
AG	-0.643	-0.209	0.149	1.000				
MDRY	0.010	-0.026	-0.361	-0.156	1.000			
TRAN	0.116	0.227	0.326	-0.183	-0.297	1.000		
WILD	0.539	0.382	-0.158	-0.207	-0.336	-0.394	1.000	
YDRY	-0.348	-0.589	0.095	-0.127	-0.206	-0.241	-0.273	1.000

Table 9. Road Density Independent Variable Correlations

	Elevation	**Distance to LGR**	**Length at Tagging**	**Road Density**
Elevation	1.000			
Distance to LGR	0.799	1.000		
Length at Tagging	-0.194	-0.076	1.000	
Road Density	-0.613	-0.528	0.297	1.000

Figure 1. Regional Map of Release Sites
(in pittag map 5-98.doc)

Figure 2. Comparison of lngeo and classification variables

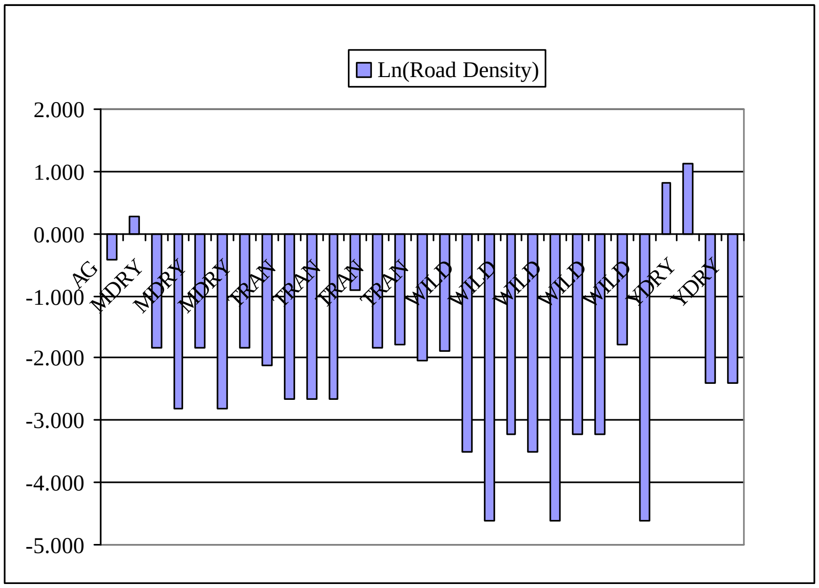
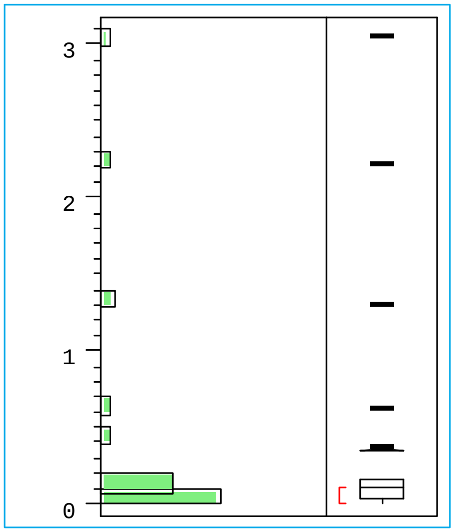


Figure 3. Distribution of Geometric Mean Road Density and ln(Density)

Geometric

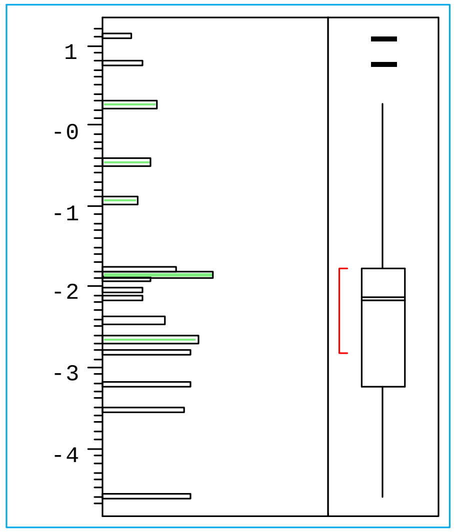


Quantiles

maximum	100.0%	
	99.5%	
	97.5%	
	90.0%	
quartile	75.0%	
median	50.0%	
quartile	25.0%	
	10.0%	
	2.5%	
	0.5%	
minimum	0.0%	

Moments

LN(geodens)



Quantiles

maximum	100.0%	
	99.5%	
	97.5%	
	90.0%	
quartile	75.0%	-1.7720
median	50.0%	-2.1203
quartile	25.0%	-3.2189
	10.0%	-3.5066
	2.5%	-4.6052
	0.5%	-4.6052
minimum	0.0%	-4.6052

Moments

Figure 4. Example of Bootstrapped parameter values

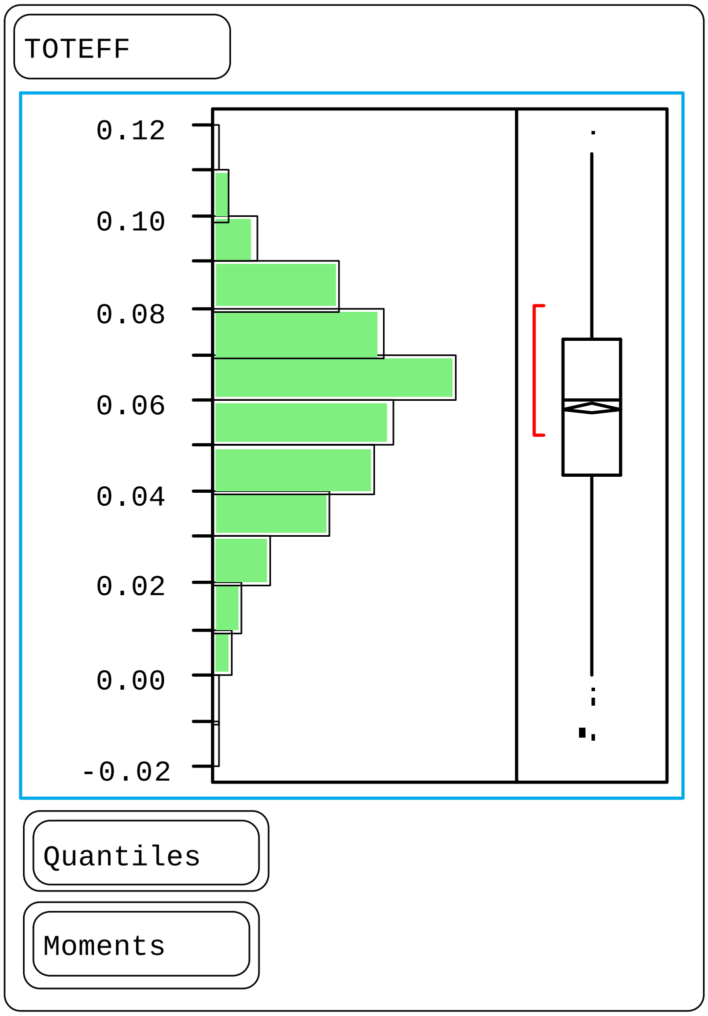
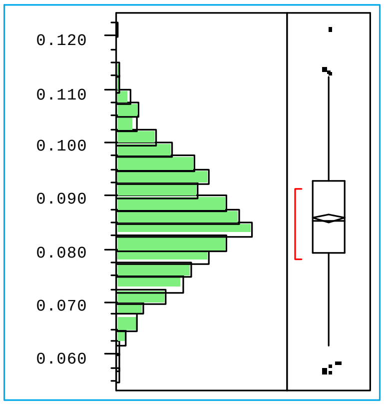


Figure 5a. Distribution of Parameters for Habitat Clusters – "AG"

Linear

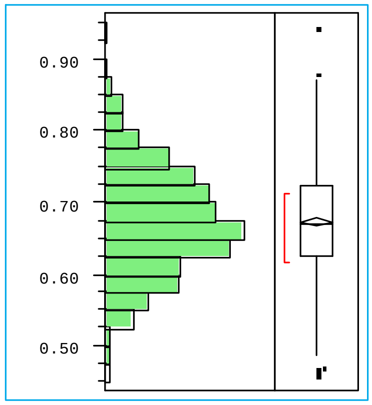


Quantiles

maximum	100.0%	0.12148
	99.5%	0.11247
	97.5%	0.10652
	90.0%	0.09869
quartile	75.0%	0.09295
median	50.0%	0.08561
quartile	25.0%	0.07936
	10.0%	0.07357
	2.5%	0.06710
	0.5%	0.06209
minimum	0.0%	0.05716

Moments

Logit

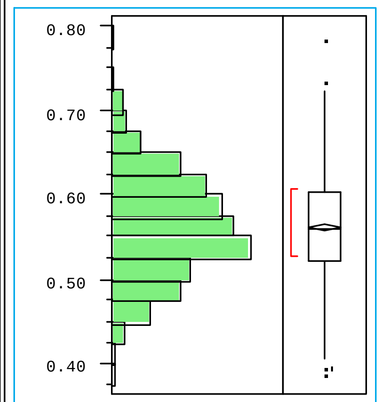


Quantiles

maximum	100.0%	0.94327
	99.5%	0.86411
	97.5%	0.82838
	90.0%	0.76754
quartile	75.0%	0.72419
median	50.0%	0.67042
quartile	25.0%	0.62616
	10.0%	0.58052
	2.5%	0.54006
	0.5%	0.49118
minimum	0.0%	0.46141

Moments

Poisson



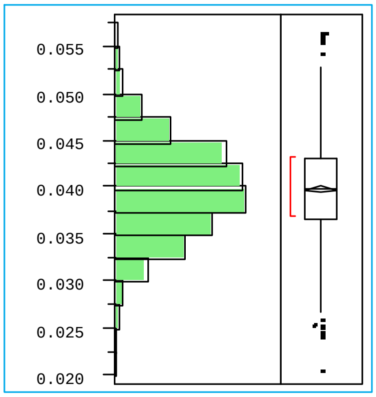
Quantiles

maximum	100.0%	0.78352
	99.5%	0.72071
	97.5%	0.68994
	90.0%	0.64038
quartile	75.0%	0.60461
median	50.0%	0.56011
quartile	25.0%	0.52272
	10.0%	0.48509
	2.5%	0.45149
	0.5%	0.41206
minimum	0.0%	0.38861

Moments

Figure 5b. Distribution of Parameters for Habitat Clusters – “MDRY”

Linear

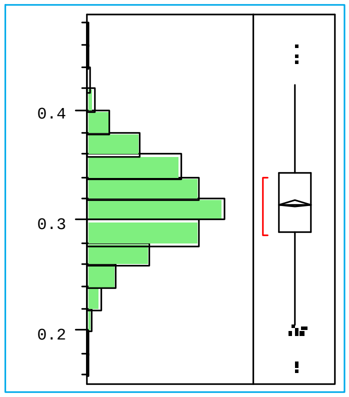


Quantiles

maximum	100.0%	0.05660
	99.5%	0.05431
	97.5%	0.04981
	90.0%	0.04640
quartile	75.0%	0.04314
median	50.0%	0.03989
quartile	25.0%	0.03651
	10.0%	0.03323
	2.5%	0.03021
	0.5%	0.02533
minimum	0.0%	0.02066

Moments

Logit

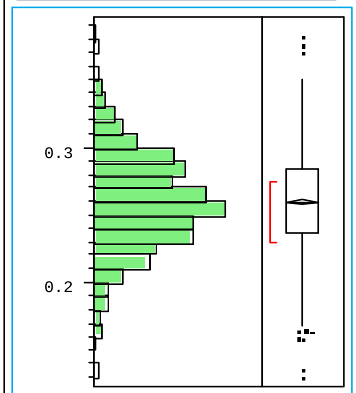


Quantiles

maximum	100.0%	0.46083
	99.5%	0.42406
	97.5%	0.39603
	90.0%	0.36630
quartile	75.0%	0.34580
median	50.0%	0.31539
quartile	25.0%	0.29003
	10.0%	0.26608
	2.5%	0.23582
	0.5%	0.20018
minimum	0.0%	0.16537

Moments

Poisson



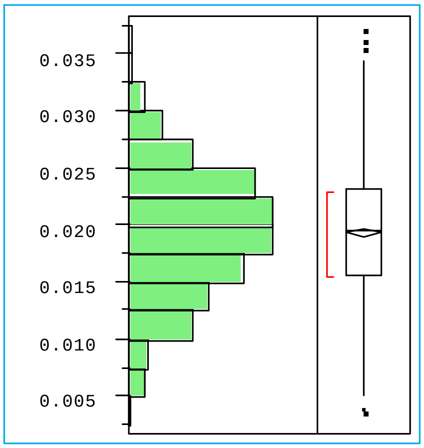
Quantiles

maximum	100.0%	0.38269
	99.5%	0.35015
	97.5%	0.32781
	90.0%	0.30183
quartile	75.0%	0.28382
median	50.0%	0.25892
quartile	25.0%	0.23753
	10.0%	0.21678
	2.5%	0.19067
	0.5%	0.16326
minimum	0.0%	0.13021

Moments

Figure 5c. Distribution of Parameters for Habitat Clusters – "TRAN"

Linear

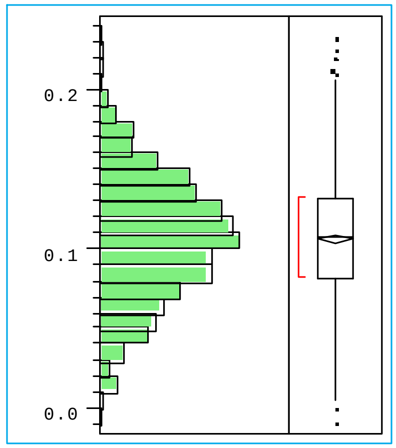


Quantiles

maximum	100.0%	0.03721
	99.5%	0.03432
	97.5%	0.02993
	90.0%	0.02608
quartile	75.0%	0.02329
median	50.0%	0.01952
quartile	25.0%	0.01569
	10.0%	0.01164
	2.5%	0.00832
	0.5%	0.00559
minimum	0.0%	0.00371

Moments

Logit

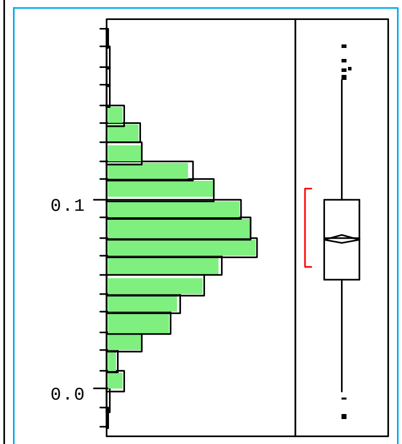


Quantiles

maximum	100.0%	0.23252
	99.5%	0.21226
	97.5%	0.18037
	90.0%	0.15428
quartile	75.0%	0.13221
median	50.0%	0.10751
quartile	25.0%	0.08124
	10.0%	0.05445
	2.5%	0.03025
	0.5%	0.01088
minimum	0.0%	-0.0076

Moments

Poisson



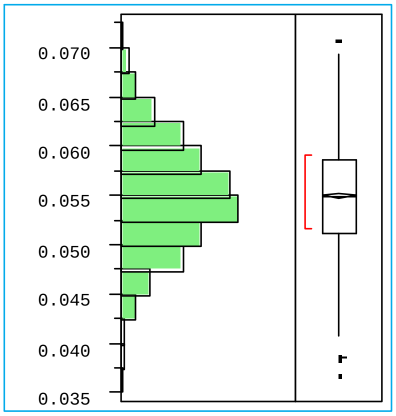
Quantiles

maximum	100.0%	0.18248
	99.5%	0.16567
	97.5%	0.13982
	90.0%	0.11815
quartile	75.0%	0.10022
median	50.0%	0.07999
quartile	25.0%	0.05839
	10.0%	0.03677
	2.5%	0.01792
	0.5%	0.00202
minimum	0.0%	-0.0134

Moments

Figure 5d. Distribution of Parameters for Habitat Clusters – “WILD”

Linear

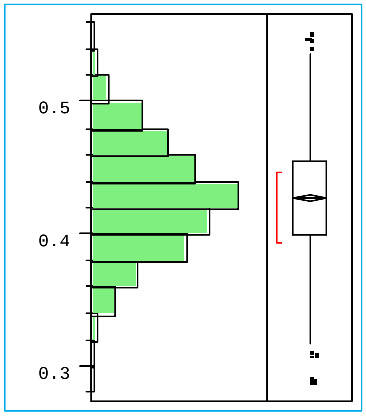


Quantiles

maximum	100.0%	0.07093
	99.5%	0.06902
	97.5%	0.06625
	90.0%	0.06229
quartile	75.0%	0.05870
median	50.0%	0.05499
quartile	25.0%	0.05123
	10.0%	0.04831
	2.5%	0.04429
	0.5%	0.03890
minimum	0.0%	0.03700

Moments

Logit

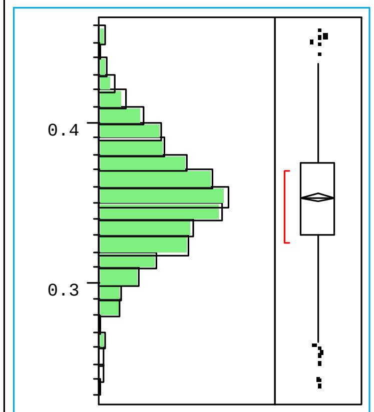


Quantiles

maximum	100.0%	0.55310
	99.5%	0.54228
	97.5%	0.50866
	90.0%	0.48158
quartile	75.0%	0.45547
median	50.0%	0.42770
quartile	25.0%	0.39998
	10.0%	0.37684
	2.5%	0.34561
	0.5%	0.30963
minimum	0.0%	0.28909

Moments

Poisson

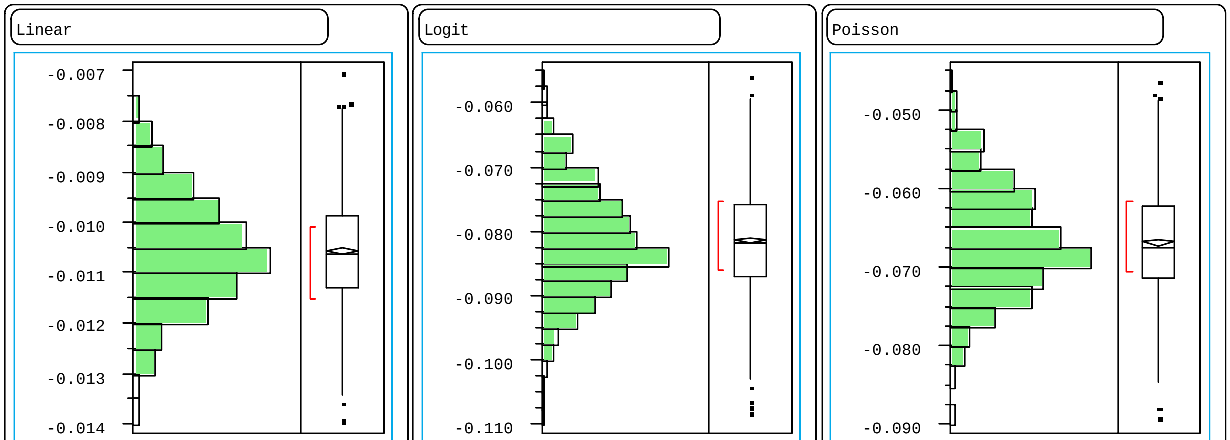


Quantiles

maximum	100.0%	0.45914
	99.5%	0.45043
	97.5%	0.41933
	90.0%	0.39854
quartile	75.0%	0.37633
median	50.0%	0.35326
quartile	25.0%	0.33098
	10.0%	0.31111
	2.5%	0.28520
	0.5%	0.25684
minimum	0.0%	0.23720

Moments

Figure 6. Distribution of Parameters for Road Density



Linear

Quantiles

maximum	100.0%	
	99.5%	-0.0077
	97.5%	-0.0084
	90.0%	-0.0092
quartile	75.0%	-0.0098
median	50.0%	-0.0106
quartile	25.0%	-0.0113
	10.0%	-0.0119
	2.5%	-0.0128
	0.5%	-0.0134
minimum	0.0%	

Moments

Logit

Quantiles

maximum	100.0%	-0.0556
	99.5%	
	97.5%	-0.0652
	90.0%	-0.0707
quartile	75.0%	-0.0757
median	50.0%	-0.0819
quartile	25.0%	-0.0868
	10.0%	-0.0915
	2.5%	-0.0973
	0.5%	-0.1028
minimum	0.0%	-0.1082

Moments

Poisson

Quantiles

maximum	100.0%	-0.0463
	99.5%	-0.0489
	97.5%	-0.0534
	90.0%	
quartile	75.0%	-0.0621
median	50.0%	-0.0673
quartile	25.0%	-0.0713
	10.0%	-0.0751
	2.5%	-0.0799
	0.5%	-0.0826
minimum	0.0%	-0.0889

Moments